METAPHORS AND PARADIGMS OF TEAM COGNITION: A TWENTY YEAR PERSPECTIVE

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There are many ways to think about the occurrence of team cognition, how it plays out among team members, how technology and context impact its expression, and how interdependencies develop given changing circumstances and plans. Our intent is to develop a generic metaphor with systematic expansions that provide a thought simulation to further enhance researcher's conceptualization of teamwork and team cognition. Knowledge can be constructed using a metaphorical view that can help develop new constructs within team cognition theories, models, technologies, simulations, and contexts. The paper looks at specific condensation of selected constructs by reviewing the author's involvement in team cognition paradigms, simulations, and research (TRAP, CITIES, JASPER, DDD). Perspectives developed across twenty years of experience are utilized to highlight similar yet differing approaches to team cognition while yielding guidance and lessons learned in designing scaled world simulations.

INTRODUCTION

Within the purview of human factors and cognitive systems, solving many of today's complex problems revolves around what has been identified as team cognition. With the advent of a contemporary digital global society, team cognition plays a much greater role than in the past in facilitating successful performance in newer domains (e.g., uninhabited air vehicles, homeland security and defense, satellite operations, intelligent highway systems, battle management, and wireless communications). Team cognition can be thought of as a general metaphor to understand how users are shaped by the constraints of technology, society, work, and stress. The goal of this paper is to (1) describe this metaphor then (2) explore how this metaphor maps to four team cognition research paradigms (3) review how these paradigms advance team cognition.

An Evolutionary Phenomena

Team cognition has not just arrived on the scene. It has evolved as a strange attractor from several perspectives of converging research. This evolution is representative within my own team research during the last twenty years (a majority of which was conducted at a government laboratory and more recently in academia). In a historical review of the USAF Human Engineering division, McNeese (1998) suggests that the last four decades of team research can be viewed as a layered model of development spanning from psychology to technology to fieldwork to cognitive systems engineering to a socio-cultural emphasis. Research paradigms tend to couple strongly with these progressive developments and in turn reflect the zeitgeist operative in a given decade. Two invariant goals that influence team cognition research are: a) the *socio-technical implications* of the team process and b) the salience of the *applied setting* (i.e., the situated context that drives the research study).

One lesson learned is that historical cycles of socio-technical systems research tend to align strongly with team activities required for a given era and context of warfare. Yet, one element that persists throughout different eras is the command post (albeit it in various forms). At the heart of command post operations is acquiring up-to-date information and distributing intelligence across various teams "portals". Early foundations (1950s-1960s) actually viewed these operations as team-centric (e.g., Kincade & Kidd, 1958) and research developed using the perspective of social psychology or experimental psychology but typically not both.

As the cognitivist revolution gained popularity in the 1970s, human information processing models became the de facto standard for thinking about individual human performance. Visionary thinkers began to look at team performance using inherited notions from individual cognition (e.g., mental models,) and this still exists today (Hintz, 2001). In turn, the melding of social, team, and cognitive concepts spawned initial team cognition research.

At some point the convergence of these types of psychology migrated towards a more technological substrate, *human-machine interfaces*. Beginning work in this new interdisciplinary area integrated social psychology, decision making, and human-machine interfaces, and influenced initial work on our first team cognition paradigm, TRAP, in the mid 1980s. As human-computer interaction gained prominence (computers replaced older machine elements), the use of computers to support collaboration distilled another new direction. Several innovative paradigms developed these ideas to formulate new research agendas and investigations in team cognition (e.g. CITIES, Wellens, 1993).

Another perspective influential in this mix was field studies research of real world command posts (see McNeese, 1998) which elevated the importance of context, distributed work, cognitive systems engineering, and socio-cultural variables in the formation of collaborative technologies. Today, we have swung full circle and are using the Jasper paradigm to test how socio-cultural factors impact team cognition (e.g. team peacekeeping operations) while using collaborative technologies (McNeese , 2001).

Basic Concepts

Team cognition very much evolved through the influence of contextual variety, the existing zeitgeist of a decade, and socio-technical systems coupled to military advancements. *Team cognition* implies that cognition is constructed through distributed, emergent activities using various sources. Activities are carried out by actors who in turn work together for joint purposes or goals although intentions may be mutually adapted according to context. Actors work co-jointly and form levels of interdependence, trust, and agility. They utilize objects and resources that are distributed within their working context engaging frequently in problem solving, situation assessment, planning, decision making, learning, articulation, and acting. Objects may include technologies and tools that support team activities, sense making, and actions. Activities may be shared by an actor, alternatively, actors may be shared across an activity to pursue what is demanded in a situation. Demands may require fast paced team adaptation that change team member roles and tasks across the team orchestration. Dependent on what is needed, demanded, available, shared, and accessible, team cognition can take different forms for different reasons and may vary across setting, place, and individual differences. Indeed, the contextual surround of an interacting team, the interdependent cognitive processes, as well as the socio-psychological and socio-cultural dimensions of team cognition are very important considerations in research and design.

As described, team cognition bears much resemblance with terms denoted by similar areas such as situated cognition (Lave & Wenger, 1991); socially shared cognition (Resnick, Levine, Behrend, 1991); cognition in the wild (Hutchins, 1995). In particular, distributed cognition (Salomon, 1993) is highly related. Lave expressed this as: "Cognition observed in everyday practice is distributed -stretched over, not divided-among mind, body, activity, and culturally organized settings" (Lave, 1988, p. 1).

For nearly two decades our research has encountered and investigated various elements of team cognition, and how collaborative technology tools may be adapted to support cooperative activities (Whitaker, Selvaraj, Brown, & McNeese, 1995; McNeese, 2002). Through our observations of team cognition, we know that even under normal circumstances, with homogenous team members, tensions and conflicts often arise. Tensions, conflicts, and even stress-related events can make *access*, *transfer*, *assessment, and sharing* of knowledge difficult. When a team is heterogeneous (e.g., in nationality, ethnicity, or culture), integrating multiple knowledge can be even more daunting. Add to this the constraint of time-stressed decision making (Wilson, McNeese, & Brown, 1987) and much pressure is placed on the team to meld their cognition together into a harmonious operation. Without individuals in a team accessing and contributing unique knowledge (i.e., knowledge that other team members are not aware of or not able to access), the viability and dynamics necessary for team in complex situations (requisite variety) will not materialize. We begin with a metaphor to consider these concepts.

THESIS

A Metaphor for Team Cognition

Consider a player who has been given a jigsaw puzzle and asked to assemble individual pieces to formulate the whole. For the sake of this thought simulation, the player is working with two other team members to solve the problem. Solving the jigsaw puzzle is often an ill-structured activity in the sense that the objective is to fit pieces together that are interlocking (*interdependent*) and to develop clusters which reduce the ill structure and, in turn, reduce some of the uncertainty. A puzzle thus consists of objects or entities that have information value and may be combined with other objects in interdependent ways. As interdependencies are uncovered and as more clusters (i.e., multiple objects joined together based on a given informational value) are formed, differentiation and convergence occur and enhance the agent's intent. As more structure emerges through differentiation, players gradually determine what goes where—how individual pieces fit into clusters and how clusters compose the wholistic imagery. One strategy that players often use is the alignment of pieces that have a common line of sight (thought) (e.g., a puzzle border piece which has a straight side that indicates it is a border). A player knows a border piece is to be joined with other border pieces to form the border. As borders are formed by members, the boundary conditions—or objects—begin to become visible. This adds to the structure to enhance the *common ground of understanding*. In real world group problems, *sensemaking*—a meaningful integration of sensory data, perception, and cognition focused on selected elements of a situated event—may also occur along a uni-dimensional piece of understanding, such that several team members may link together their knowledge along this common line. That initial link facilitates more structure and perhaps invites more thoughts and questions, while moving the group toward a better solution and opportunities for sharing unique knowledge. The perception of new, additional structure in the situation affords using knowledge that otherwise could not be integrated. The team is beginning to articulate a common ground of understanding as to how various pieces fit together. This often is the case in military command and control problems, where data, information, knowledge, beliefs, and perceptions of multiple team members must "fit together" to make sense out of the situation (McNeese & Rentsch, 2001).

In contrast to the simple jigsaw puzzle metaphor, the real world context of team cognition has many more thorny components including temporal, spatial, and cultural qualities. Data, information, and knowledge tend to be separated by time, space, and action. Thought coupling may occur before all of the information has been collected. And, what has been collected may have a brief half-life; in other words, it may be "old news." Knowledge across members may be highly interdependent in terms of how it induces a solution or there may be uncertain interdependencies among team member's knowledge, making the probability for unintended consequences much greater. Under real-world constraints, the temporal qualities may put great time pressure on members to knit together "what they have available" to come up with the "best shot they can make at the time." Additionally, spatially distributed members cause a number of additional fractures in the common ground of understanding. Distributed cognition can also occur, with synchronous or asynchronous options making feedback conditional. Unlike the jigsaw puzzle, there are ill-defined attributes in everyday cognition that often make problems intractable and unsolvable, or more catastrophically, result in errors, mistakes, or emergency conditions.

Returning to the jigsaw example, note that it is really an ill-structured, but well-defined collocated cognition problem. It is better defined than everyday cognition activities (and military domains), because all of the information pieces are provided at the start. The box lid shows the image that is to be reconstructed; therefore, the team has a common, shared goal. The team works with defined interdependence and stabilized information in a face-to-face, collocated environment where typically there is little time pressure to complete a solution. Likewise, the solution is reinforced as the invisible translates to the visible. *The perception emerges as a function of building it.* One of the chief strategies involves contrast and comparison processes used to perceptually differentiate the problem. Members typically look at the picture on the jigsaw box and then look at individual pieces to begin forming groupings and/or border connections. This is conceptually similar to team members using (seeing) mental models to interpret the bits and pieces of perception that enter their world. In cases where the world is both ill structured and ill defined, everyday cognition may be challenging and may demand much differentiation, articulation, and assimilation in order for a common ground of understanding to emerge. This is especially true if team members work co-jointly and are of varying backgrounds [i.e., race, culture, age, gender, etc.]. Team members may also access previous knowledge (perhaps a component of their mental model) to increase progress on the construction and they can jointly search and remember different pieces based on shape, potential fit, color, and partial scenery.

FINDINGS

The previous section put forth a simple metaphor for team cognition to elaborate basic processes, thorny issues, and impediments to how team cognition might incur (see table 1). Over the last two decades my colleagues and I have been involved in four specific research paradigms that highlight and instantiate similar and different elements of the metaphor.

Research Paradigms for Studying Team Cognition

Empirical research based on each paradigm is intended to inform / influence the design of collaborative technologies for projected fields of practice. The paper will review the following paradigms and what we have learned from their *use*. Each paradigm can be classified as to what context drives its development, what technology focus is investigated, what theory is utilized, and what modeling technique is embedded within a simulation. For each paradigm given subsets of team cognitive processes and thorny issues may standout in its use. First, we point out what is common across these research paradigms. They all portray simulations of team cognition (however some are distinctively scaled worlds while other or not).

Table 1. Elements of the Team Cognition Metaphor

Basic-Level Team Cognition Processes

- assemble problem clusters by monitoring member's work
- respond to requests of initiated problem states
- formulate a whole via individual and team understanding
- establish co-dependence with others for interlocked acts
- coordinate ill-structured activities
- reduce uncertainty given ill-structure
- team differentiation/convergence to clarify actors' intent
- team interpretation of images to know what is "next"
- utilize and advance plans/strategies across member roles
- members alternatively engage in joint perceptual contrast/comparisons to construct meaning
- teams exploit information value of objects to plan acts
- common ground established via alignment, sensemaking
- team selects attention to tasks per salience of events
- knowledge links formed among members enhance articulation about events or objects
- team use mental models to quicken joint response, and understand other member's cognition
- teams allocate joint resources under their control to obtain objectives and adapt to new problem states

Thorny Issues

- separated by time, space, culture
- first team thoughts often in error -- weak information
- information collection coordinated across multiple cognitive processes
- derived knowledge based on "half-life" information leads
- uncertain knowledge can exist in any given member and in turn can lead to unanticipated consequences
- knowledge is inert /cannot be accessed or shared
- time pressure demands quick knitting together of only "what is available" at a moments notice
- "best shot" prognostications must be coordinated with care
- distributed (vs. collocated) place fractures common ground
- member feedback in distributed settings is conditional, typically given with lower bandwidth
- lack of initial information creates ill-defined messy work
- team stress and emotion masks effectiveness, causes instability, and invites work blockages
- different member cultures challenges situation awareness

Simulations are composed of multiple subtasks sometimes with goal conflict. In each simulation very small groups are used (2-4 members). Each simulation requires the use of computers to engage the task. The embedded tasks demand time-stressed responses. Having indicated the common attributes it is also instructive to mention distinctive differences. Some paradigms are highly naturalistic and context-driven (JASPER, DDD, CITIES) while others test more abstract abilities (TRAP). Some are highly computer-dependent (CITIES, DDD, TRAP) while others are not. Each paradigm requires varying degrees of perception and cognition.

Finally, the social orchestration demands were different per paradigm.

TRAP (Team Resource Allocation Problem, Brown & Leupp, 1985) is a 3-person team task that assesses members dynamically processing information and distributing multi-valued resources. As such it focuses on basic processes involving team allocation of resources, reduction of uncertainty across members, and team differentiation / convergence to clarify actors intent. Thorny issues include team members separated in time and space, wherein first thought couplings need error correction and time pressure causes members to knit together only what is available for unique, dynamic time windows. Demands focus on trading off individual with team goals given differing levels of uncertainty. TRAP simulated abstract team cognition within an operational command and control setting. Studies utilizing TRAP (e.g., Wilson, et al., 1987) yielded early empirical data for two socio-technical implications: group decision support systems and small versus large screen displays. Major variables employed were group versus individual displays, spatial versus verbal representations, and the presence or absence of decision heuristics. Outcomes included total team performance measure, team workload, and response times. TRAP laid foundations for other research task elements that would continue, including the role of dynamic interdependencies as defined by task structure, team modeling, and team workload. It used an internal mathematical model to emulate user-team decision making. Results showed the importance of shared versus isolated settings and how knowledge representation impacts team performance in those settings.

CITES (C^3 Interactive Task for Identifying Emergent Situations, Wellens 1993) assesses hypotheses about dynamic decision making and information fusion in complex, emergent task scenarios (within and across teams). Basic processes include teams exploiting the information values of objects to plan acts while being codependent on other teams and team members interlocked actions during team resource allocations for selected cognition of priority events. Thorny issues involve team stress and emotions which mask effectiveness and invoke work blockages as members try to coordinate their "best shot" prognostications with conditional feedback from interdependent roles. The theoretical orientation evaluates psychological distancing theory in an emergent command and control setting. A primary task demand requires teams to recognize the emerging crises in a situated problem. CITIES provided an early study on team situational awareness and spotlighted differences among team cognition and team performance outcomes given conditions of communication (e.g. face-to-face, video teleconference, phone, email) The socio-technical components of the paradigm integrated (1) electronically-mediated communication systems (2) intelligent team aids (3) information visualization (avatars). In contrast to TRAP which utilizes abstract representations, CITIES contains a realistic, crisis management problem requiring police and fire crews to pool information to make complex decisions. The task lent itself to multiple measurements including process analysis of videotapes, team physiological workload, and speech acts; all innovations for assessing team situational awareness in the context of psychological distancing theory.

JASPER (CGTV, 1997) explores how cooperative work groups utilize perceptual contexts and metacognitive processes as a basis for transferring knowledge to similar problem domains (McNeese, 2000). The context behind Jasper involves a search and rescue mission involving multiple logistic and transportation constraints that involve *distance = rate x time* physics problems. Its theoretical backdrop is predicated on knowledge acquisition and analogical transfer in situated learning (McNeese, 2000). Basic processes require teams to assemble pieces and formulate subproblems while developing a common ground through alignment / sensemaking. Thorny issues focus on inert knowledge that may be hard for members to access while interacting in distributed places which in turn impact understanding, especially when team members have differing cultural backgrounds. JASPER has demands that require subjects to problem find and subgoal complex elements together to generate the best solution. Unlike CITIES and TRAP, JASPER uses situated problem components by videotaping actual scenes from the real world and presenting them to teams as representation of the problem (a perceptual macrocontext). Subjects solve a challenge problem as they access scenes from the video while integrating different mathematical constructs. Unlike the other tasks, JASPER does not specify team member interdependencies. In fact, studies are conducted to compare how groups are different from individuals in addressing levels of cognition. Jasper has been used to look at computer-supported cooperative learning, team metacognition, and team schema similarity measurement. Results show individuals focus on the perceptual macrocontext while teams emphasize metacognitive processes more which impact transfer performance differently.

DDD (Distributed Dynamic Decisionmaking, Hess, MacMillan, & Serfaty, 1999) is a complex computer-supported team simulation that we adapted to study team member schema similarity (McNeese, Rentsch, & Perusich, 1999) – but unlike Jasper – it utilizes a task structure requiring team interdependence. Basic processes in DDD require codependence with other members to formulate interlocked plans wherein teams use mental models to quicken joint responses to understand each member's actions. DDD thorns include derived knowledge that is based on multiple information leads that can have a brief half-life as well as lack of information can create ill-defined messy work situations. Like TRAP and CITIES, DDD requires timely allocation of team member resources. Unlike the other tasks DDD is derived from actual AWACS command and control work analyses. Similar to JASPER, DDD requires team metacognition and is performed under time stress. We used the DDD task to look at theory involving team-member schema similarity and group-computer interfaces utilizing fuzzy cognitive aids (McNeese et al., 1999). Outcomes include team effectiveness, offense-defense scores, average latencies for critical events, mishaps.

CONCLUSIONS

The use of a metaphor for team cognition facilitates the simulation and testing of initial ideas and concepts in a variety of domains to allow researchers to generate new hypotheses of how people interact together with the support of technologies. The metaphor may also be useful for considering how to construct scaled world simulations and understand the socio-cognitive-cultural factors that pervade overall performance. Differing elements of this metaphor have been operationalized through two decades worth of research involving development of unique team research paradigms. Table 2 demonstrates the focus, values, and impacts for each of these paradigms, and how they have contributed in general to expanding team cognition research from a human factors perspective. As one peruses this table there are poignant questions that must be asked as one develops appropriate scaled worlds for a domain. In conclusion, the comparisons of these different paradigms demonstrates the necessity of keeping diversity as a core value by utilizing diverse fields of practice, methods, measures, subjects, and task types.

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Table 2. World of Coverage in Team Cognition Paradigms

	Context	Technology	Theory	Model
TRAP	NORAD Command & Control	LGDs and Decision Aids	Team Performance/ Distributed Cog.	Internal Mathematical Model
CITIES	Crisis Management Fire-PoliceTeams	Electronically-Mediated Comm./Avatars	Team SA / Team-to-Team Performance	Expert Systems
JASPER	Search & Rescue Mission w. Ultralight Plane	Computer Supported Coop.Work	MetaCognition Perceptual Lrng. Knowledge XFer	Problem Space Objects
DDD	AWACS CREW Battle Management	Mixed Initiative Intelligence (AI)	Team Mental Models	Fuzzy Cognitive Maps